

Coal Loss Reconciliation and Conditional Recovery Scenarios for an Open-Pit Coal Seam in Jambi, Indonesia

Indah Permata Sari¹, Heri Prabowo^{1*}, Jukepsa Andas¹, Rangga Agung Pribadi Heriawan¹

ABSTRACT

Coal recovery in open-pit mines is commonly judged against the 90% mining-recovery planning figure of Indonesian good-mining-practice regulation, although survey and weighbridge tonnages originate from different measurement systems. This study reconciled survey-based in-situ tonnage (Ts) with weighbridge tonnage (Tc) for Seam 2, Pit B, Jambi, Indonesia, in January–February 2026, allocated the apparent discrepancy to three components, and calculated conditional recovery targets. Ts was 28,536.03 tons and Tc 24,114.08 tons, giving an apparent discrepancy of 4,421.95 tons (15.50%) and a coal recovery of 84.50%. In the base case, hauling (41.37%, estimated) exceeded other factors (32.25%, residual) and loading point (26.39%, assumption-based), but this ranking reversed at bucket fill factors below 0.943, marginally above the observed mean of 0.942; recovery would reach 90% at an in-situ density of 1.183 tons/m³. Reaching 90% requires recovering 1,568.35 tons, a 35.47% reduction of the discrepancy, which is an arithmetic target rather than a tested outcome.

Keywords

Coal losses; Coal reconciliation; Haulage discrepancy; Mining recovery; Sensitivity analysis

¹ Department of Mining Engineering, Faculty of Engineering, Universitas Negeri Padang
Jl. Prof. Dr. Hamka, Air Tawar, Padang 25131, Indonesia

* Corresponding Author: heri.19782000@ft.unp.ac.id

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INTRODUCTION

Coal is a non-renewable resource, so every ton of reserve that is extracted but not delivered is an irreversible loss of value. Not all coal defined in the geological model reaches the stockpile: the portion lost along the mining chain, from the pit to the shipping stage, is termed coal losses. These losses reduce salable tonnage and reserve recovery without reducing the overburden-stripping cost that has already been incurred [1].

Indonesian good-mining-practice regulation provides a measurable benchmark for such losses. Decree of the Minister of Energy and Mineral Resources No. 1827 K/30/MEM/2018 (hereinafter Kepmen 1827/2018) requires an open-pit feasibility study to plan a mining recovery of at least 90% (Appendix VII, Part D, item 1.a.1)a, p. 347) [2]. Because the decree defines mining recovery as production divided by reserves (Part C, item 11, p. 347) [2], the 90% value is a planning figure with a reserve denominator. In this study it is used only as a benchmark for the ratio Tc/Ts, and the consequences of this choice are stated in the Research Limitations.

At Seam 2 of Pit B in Mandiangan District, Sarolangun Regency, Jambi Province, the weighbridge tonnage recorded for January–February 2026 was lower than the tonnage converted from the mined-out survey, indicating a coal recovery below the 90% benchmark. Such a shortfall cannot be attributed directly to operational stages. The survey-based in-situ tonnage (Ts) and the actual hauled tonnage recorded by the weighbridge (Tc) come from different measurement systems, so their difference may also contain timing offsets, density and moisture effects, and measurement error. The discrepancy must therefore be decomposed and tested for robustness before it is used to direct improvement efforts.

Recovery below the benchmark has been reported repeatedly for Indonesian coal pits: coal losses of 22.77% at PT Hutamas Koado in the same regency [3], 19.43% in May 2019 at PT Kaltim Prima Coal [4], 10.35% at PT Muara Alam Sejahtera [5], and 2.9–4.0% per month at a mine that compared survey and truck-count tonnage [6]. These figures, however, rest on different measurement boundaries, namely extraction only at a South African colliery [1], coal getting to barging [7], survey to weighbridge [5], and truck count [6], while a further study compared survey-based and truck-count-based production estimates without allocating losses [8]. Where losses were divided into operational components [5]–[7], the loading point was the largest contributor [4], [5], and the only simulated loss reduction was confined to the loading point [4]. In Jambi Province, published work on coal operations has addressed production planning, such as mining-sequence optimization, rather than loss quantification [9].

Across these studies, losses are reported as point estimates. The Klipspruit study gives no error bounds [1], and whether the other studies report uncertainty was not assessed here. The gap addressed in this study is therefore not the absence of loss figures but the absence, in the studies reviewed, of an explicit test of how strongly a Ts–Tc component allocation and a 90% recovery target depend on inputs that are assumed rather than measured, namely the bucket fill factor, coal density, residual roof thickness, and inventory timing.

This single-site applied case study adapts the Ts–Tc subtraction and component decomposition used in earlier coal-loss studies [5] and adds three elements: (i) labelling each quantity as measured, estimated, assumed, or residual; (ii) a sensitivity analysis of the component ranking and of coal recovery to the bucket fill factor, density, and roof thickness; and (iii) recovery-target scenarios reported as conditional arithmetic results. No new estimation method is claimed. The objectives are (1) to reconcile Ts with Tc for January–February 2026 and report the apparent discrepancy and coal recovery; (2) to estimate the loading-point, hauling, and other-factor components and test whether their ranking is robust to the unmeasured inputs; and (3) to calculate the tonnage and component reductions required to reach 90% recovery as a conditional target. The engineering feasibility of these reductions lies outside the scope of the study because attainable reduction limits were not measured.

METHOD

Research Design

This study used a descriptive quantitative design, which describes measurable quantities from numerical data without manipulating variables or testing causal relationships. The design suits the problem because coal losses and recovery are measurable quantities and no treatment was applied to the mining activity. The analysis proceeded in four linked stages, namely reconciliation, decomposition, robustness testing, and recovery-target calculation, supported by descriptive operational data, as summarized in Figure 1.

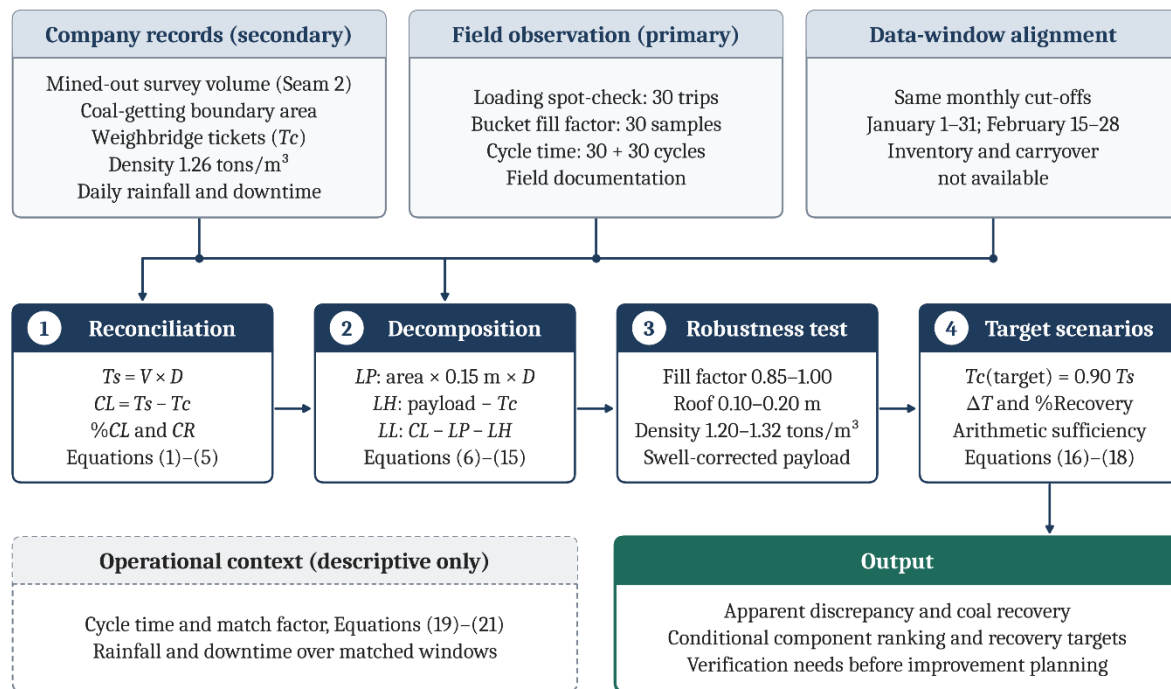


Figure 1. Research workflow linking the data sources to the reconciliation, decomposition, robustness test, and recovery-target scenarios. Shaded boxes are inputs; numbered boxes are analytical stages.

Figure 1 shows that company records and field observations enter the analysis at different stages. The survey volume and weighbridge tickets alone define T_s , T_c , and the apparent discrepancy, whereas the spot-check and fill-factor observations are needed only to allocate that discrepancy among components. This separation determines the evidential status of each result reported later.

Study Site and Data Sources

The study was conducted in a coal mining business license area in Mandiangin District, Sarolangun Regency, Jambi Province, operated by a mining contractor whose name is withheld. The company's survey team produced the survey volumes and the coal-getting boundary area (Total Station surveys processed in Minescape) and supplied the weighbridge truck-count tickets. The authors carried out the loading spot-check and the cycle-time and fill-factor observations, and checked the T_s conversion and the monthly ticket sums. The company granted permission for the research and approved publication of the anonymized records and field photographs without naming the company.

The object of the study was coal mining on Seam 2 of Pit B during January–February 2026, covering the entire coal volume extracted according to the mined-out survey and the 1,042 dump-truck trips recorded in the weighbridge tickets. One Sany SY365H excavator with a heaped bucket capacity of 1.6 m³ (company specification) loaded the coal, and Shacman F3000 dump trucks with a rated load of 20–30 tons hauled it approximately 1,000 m from the mining front to the stockpile. Nine units (DK-23 to DK-31) appear in the tickets but were not recorded on the same dates: of the 18 dates with ticket records, three units were recorded on 13 dates, four on 4 dates, and one on 1 date. The fleet assigned to the excavator was therefore taken as three concurrent units (range 3–4) rather than nine.

Data Collection and Data Windows

Primary data comprised a loading spot-check on 30 trips of units DK-23, DK-27, and DK-31 (390 bucket passes, 13 per trip); cycle-time measurements of 30 excavator cycles and 30 truck cycles on the same units (10 per truck unit); a bucket-fill-factor observation of 30 loading

samples; and field observation and documentation of conditions causing coal losses. The three units, three of the nine registered units, were selected by convenience sampling of trips observable during normal mining (10 per unit). Field observation covered 13 January–21 February 2026, whereas the spot-check, cycle-time, and fill-factor data were all recorded on 20 January 2026 (day shift), and the tickets for that date list the same three units. Because these three data sets come from a single day in January, they are assumed to represent the whole study period with the same excavator and trucks.

Secondary data were the Minescape survey results and boundary area, the weighbridge truck-count recapitulation, the coal density of 1.26 tons/m³, and the daily rainfall and downtime reports. The ticket records cover 18 dates (13 in January and 5 in February), all in the day shift. No ticket records exist for the other dates, so any hauling on those dates would make Tc incomplete. The weighbridge calibration and tolerance, the ticket weighing procedure and moisture basis, the survey instrument calibration, and the Minescape quality checks are not documented.

Ts and Tc were compared with the same monthly calendar cut-offs. The February survey covered only 15–28 February; according to company records, no coal getting took place on Seam 2 between 1 and 14 February 2026, and no survey or weighbridge data exist for that window. Comparing truck-count tonnage with an independent measurement over identical periods follows practice reported for another commodity [10], although identical cut-offs do not ensure that the same coal parcels are compared. Opening and closing inventories, transfers, rehandling, and the carryover of coal hauled after a cut-off were not available. Ts – Tc is therefore treated as an apparent discrepancy; no bound on carryover can be given, and any coal mined shortly before a cut-off and hauled after it would reduce the apparent discrepancy by the same tonnage.

Bucket Fill Factor and Payload Spot-Check

The bucket fill factor was determined by visual observation of 30 bucket-loading samples. One observer compared each sample with reference images of fill categories A (100–120%), B (95–110%), and C (80–95%), whose ranges follow the reference illustration [11] and overlap as printed there. Within the selected category, the observer recorded a fill percentage, so the statistics were computed from the recorded percentages rather than from category midpoints. Four samples fell in category A, 10 in B, and 16 in C (minimum 85%, maximum 103%, mean 94.17%, SD 4.62%). The value 0.95, the boundary between categories B and C, was adopted because it lies closest to the mean. Calibration against weighed loads was not available and image-based estimation [12] was not used; because a single value does not establish payload accuracy, the fill factor was varied in the sensitivity analysis.

During the spot-check, the number of bucket passes per trip was recorded, the estimated payload was calculated with Equation (11) and averaged, and the average was compared with the average weighbridge tonnage through Equation (12). A deviation of consistent sign cannot distinguish physical loss during hauling from a systematic error in the payload estimate, so the hauling loss is interpreted as an estimated allocation.

Tonnage Conversion

Coal density is the ratio of weight to volume, expressed in tons per cubic meter. The mined-out survey gives the bank (in-situ) volume, which is converted into tonnage with the in-situ density through Equations (1) and (2).

$$D = \frac{W}{V} \quad (1)$$

$$Ts = V \times D \quad (2)$$

where D is the in-situ coal density (tons/m³), W is the coal weight (tons), V is the coal volume from the mined-out survey (m³, bank basis), and T_s is the in-situ coal tonnage (tons). The company's production data give a Seam 2 bank density of 1.26 tons/m³ without the test method, sample number and location, moisture basis, or period, so the value was used as a constant. Broken coal in a bucket or truck vessel is loose, and its bulk density is lower than the in-situ density because of swell; the in-situ density therefore cannot be applied to loose volume without a conversion or an explicit assumption.

T_s denotes the tonnage converted from the mined-out survey volume of an area that has finished being mined, not a pre-mining reserve measurement, consistent with the definition used in [3] and [5]. The surveyed volume runs from the initial surface (top of the seam) to the excavation floor, so the envelope contains the coal layer left in place at the roof. For this reason the loading-point loss belongs to $T_s - T_c$, whereas coal below the excavation floor lies outside T_s .

Coal Losses and Coal Recovery

Coal losses make the tonnage hauled to the stockpile smaller than the surveyed tonnage [13]. By cause, they are grouped into geological losses arising from variations in seam thickness, partings, and seam structure [14]; mining losses from coal left on the roof and floor and coal spilled during loading; and transport losses from coal spilled along the haul road or left in the dump-truck vessel. The total loss tonnage, the loss percentage relative to T_s , and coal recovery follow Equations (3)–(5) [5].

$$CL = T_s - T_c \quad (3)$$

$$\%CL = \left(\frac{CL}{T_s} \right) \times 100\% \quad (4)$$

$$CR = \left(\frac{T_c}{T_s} \right) \times 100\% \quad (5)$$

where CL is the total loss tonnage (tons), T_c is the actual tonnage based on weighbridge data (tons), $\%CL$ is the loss percentage relative to T_s (%), and CR is coal recovery (%); CR and $\%CL$ sum to 100%. Because CL is obtained as T_s minus T_c , it also contains any difference caused by timing, density, moisture, and measurement error, and it is therefore an apparent discrepancy unless these effects are reconciled.

Decomposition of the Apparent Discrepancy

The apparent discrepancy was decomposed into three operational components, namely losses at the loading point, during hauling, and from other factors, whose sum equals the total loss tonnage [5]. The components differ in evidential status: loading-point loss is calculated from a surveyed area and an assumed thickness, hauling loss is an estimated discrepancy between a spot-check payload estimate and weighbridge tonnage, and other-factor loss is a residual.

Loading-point loss arises from seam geometry. Coal occurs as a seam bounded by a roof and a floor in direct contact with the surrounding rock, with thickness, dip, and continuity that vary with the local geological structure [14]. Open-pit excavation must follow both boundaries: excavation that stops short leaves coal in the seam, whereas excavation beyond the boundary mixes coal with waste. In this study, loading-point loss is the coal left on the roof of an area that has finished being excavated, calculated with Equations (6)–(8).

$$VLP = LLP \times TLP \quad (6)$$

$$LP = VLP \times D \quad (7)$$

$$\%LP = \left(\frac{LP}{T_s} \right) \times 100\% \quad (8)$$

where VLP is the volume of coal left at the loading point (m^3), LLP is the area of the coal-getting boundary (m^2), TLP is the thickness of coal left on the roof (m), taken from the company's operational provision, LP is the loading-point loss (tons), and %LP is the loading-point loss relative to T_s (%).

Hauling loss was estimated as the difference between the tonnage loaded, estimated at the loading point from the spot-check, and the weighbridge tonnage, as in Equations (9) and (10) [5]. The estimated payload per trip follows Equation (11), in which the bucket fill factor, the proportion of the bucket that is filled, determines the payload carried per trip [15]. The estimate is compared with the weighbridge data through the deviation in Equation (12) [7].

$$LH = (\text{Trips} \times xu) - Tc \quad (9)$$

$$\%LH = \left(\frac{LH}{T_s} \right) \times 100\% \quad (10)$$

$$xu = Na \times Kb \times FF \times D \quad (11)$$

$$\text{Deviation} = \left| \frac{xu - xtc}{xtc} \right| \times 100\% \quad (12)$$

where LH is the hauling loss (tons), Trips is the number of dump-truck trips, xu is the estimated payload per trip from the spot-check (tons/trip), Na is the number of bucket passes per trip, Kb is the heaped bucket capacity of the excavator (m^3), FF is the bucket fill factor (fraction), xtc is the average weighbridge tonnage per trip (tons/trip), %LH is the hauling loss relative to T_s (%), and Deviation is the relative deviation between the spot-check payload estimate and the average weighbridge tonnage (%). In Equation (11), D is the density applied to the bucket volume; following company convention it equals the in-situ value, which makes xu a payload-equivalent assumption. Because loose bulk density was not measured, this convention, which yields the upper end of the hauling estimate, is retained in the base case, and a swell-corrected alternative is examined in the sensitivity analysis.

Other-factor loss was obtained as a residual through Equations (13) and (14). The residual is expected to include coal submerged in or contaminated with mud during rain [16], but it also absorbs timing offsets, density and moisture effects, and every estimation error in T_s , T_c , LP, and LH.

$$LL = CL - LP - LH \quad (13)$$

$$\%LL = \left(\frac{LL}{T_s} \right) \times 100\% \quad (14)$$

where LL is the other-factor loss (tons) and %LL is the other-factor loss relative to T_s (%). Because LL is obtained by difference, the three components are not independent. The contribution of each component to the total loss tonnage is calculated with Equation (15).

$$\%Contribution = \left(\frac{\text{Losses}_{\text{factor}}}{CL} \right) \times 100\% \quad (15)$$

where %Contribution is the share of a given component in CL (%), and $\text{Losses}_{\text{factor}}$ is the loss tonnage of the component examined, namely LP, LH, or LL (tons).

Recovery-Target Scenarios

The scenario calculation determines the tonnage by which T_c would have to increase for coal recovery to reach 90%, through Equations (16)–(18). It applies to the T_s of the study window and counts only losses that could be prevented in that production; reclamation of coal already lost is not included.

$$Tc(\text{target}) = T_s \times 0.90 \quad (16)$$

$$\Delta T = Tc(\text{target}) - Tc \quad (17)$$

$$\% \text{Recovery} = \left(\frac{\Delta T}{CL} \right) \times 100\% \quad (18)$$

where $T_c(\text{target})$ is the actual tonnage required for 90% recovery (tons), ΔT is the additional tonnage that must be recovered (tons), and %Recovery is the proportion of the coal losses that must be eliminated (%). A scenario is arithmetically sufficient if the summed reductions of its target components (reduction fraction multiplied by component loss) are at least ΔT . This criterion says nothing about technical attainability, which requires component-specific upper limits on achievable reduction; because these limits were not measured, they are explored parametrically.

Loading–Hauling Equipment Match Factor

Cycle time and the match factor describe the operating conditions under which the hauling estimate was obtained. Cycle time is the duration required for a unit to complete one work cycle, calculated with Equation (19) for the loading equipment and Equation (20) for the hauling equipment [17], [18]. Equipment compatibility is assessed through the match factor in Equation (21) [19], which in this study serves only as operational context; it is neither evidence of loss nor a variable in the coal-loss calculation.

$$CT_m = T_g + T_{sl} + T_{de} + T_{se} \quad (19)$$

$$CT_a = T_{ml} + T_l + T_h + T_{md} + T_{dt} + T_r \quad (20)$$

$$MF = \frac{n_a \times CT_m \times N_b}{n_m \times CT_a} \quad (21)$$

where CT_m and CT_a are the cycle times of the loading and hauling equipment; T_g , T_{sl} , T_{de} , and T_{se} are the digging, swing-load, excavator dumping, and swing-empty times; T_{ml} , T_l , T_h , T_{md} , T_{dt} , and T_r are the truck maneuvering time at loading, loading, hauling, maneuvering time at dumping, dumping, and return times (all in seconds); MF is the match factor; n_a is the number of hauling units working concurrently with the loading unit; n_m is the number of loading units in operation; and N_b is the number of bucket loads per trip. CT_a is the sum of the timed elements; queue waiting was not timed separately, so queue time is included in CT_a only if it was recorded within T_{ml} . $MF = 1$ indicates matched operation, $MF > 1$ an excess of hauling units that may cause queuing at the mining front, and $MF < 1$ possible waiting time for the loading equipment.

Data Analysis

Data analysis was quantitative-descriptive and sequential. The mined-out survey volume was first converted into T_s , and T_c was recapitulated for January, February, and the whole period after confirming that both quantities use the same monthly cut-offs. Coal losses and recovery were then calculated with Equations (3)–(5), aggregating from tonnage sums, and the apparent discrepancy was decomposed into three components with Equations (6)–(15). Robustness was tested by recalculating the decomposition for fill factors of 0.85–1.00, roof thicknesses of 0.10–0.20 m, and in-situ densities of 1.20–1.32 tons/m³. Cycle-time, match-factor, and rainfall data were described over matched windows, and the recovery-target scenarios were calculated with Equations (16)–(18) as conditional arithmetic cases.

RESULTS AND DISCUSSION

Results

The results follow the three objectives: the reconciliation of T_s with T_c , the decomposition of the apparent discrepancy and its robustness, and the recovery-target calculation. Cycle-time, match-factor, and rainfall data are reported as operational context for the hauling and residual components.

In-Situ Tonnage and Weighbridge Tonnage

The coal volume mined during January–February 2026 was 22,647.64 bank cubic meters (BCM). With a density of 1.26 tons/m³, Equation (2) gives $T_s = 22,647.64 \times 1.26 = 28,536.03$ tons. The weighbridge recorded $T_c = 24,114.08$ tons from 1,042 trips on 18 dates. Table 1 summarizes both quantities by period, together with the ticket tonnage per trip that is used later in the hauling estimate.

Table 1. *In-situ tonnage (T_s) and weighbridge tonnage (T_c) of Seam 2, Pit B, by period*

Period	Survey window	Volume (BCM)	T_s (tons)	Trips	T_c (tons)	T_c per trip (tons/trip)
January 2026	1–31 Jan.	18,706.06	23,569.64	866	20,184.50	23.31
February 2026	15–28 Feb.	3,941.58	4,966.39	176	3,929.58	22.33
Total		22,647.64	28,536.03	1,042	24,114.08	23.14

Source: Company Engineering Department data, 2026 (processed). T_s = volume $\times$ 1.26 tons/m³. Ticket records cover 13 dates in January and 5 dates in February, all in the day shift.

January dominates the study window. Because the February survey covered only 15–28 February, the February volume was 21.07% of the January volume, and January accounts for 82.60% of the total T_s . Because T_s is proportional to D , coal recovery would equal 90% at an in-situ density of 1.183 tons/m³, so the recovery result depends directly on the density assumption.

Coal Losses and Coal Recovery

Applying Equations (3)–(5) to the totals gives $CL = 4,421.95$ tons, $\%CL = 15.50\%$, and $CR = 84.50\%$, which is 5.50 percentage points below the 90% benchmark. Table 2 shows that the shortfall occurred in both months but was larger in February.

Table 2. *Coal losses and coal recovery of Seam 2, Pit B, by period*

Period	T_s (tons)	T_c (tons)	CL (tons)	$\%CL$	CR (%)
January 2026	23,569.64	20,184.50	3,385.14	14.36	85.64
February 2026	4,966.39	3,929.58	1,036.81	20.88	79.12
Total	28,536.03	24,114.08	4,421.95	15.50	84.50

Source: Research data processing, 2026. $CL = T_s - T_c$; $\%CL$ and CR are relative to T_s .

Coal recovery was 85.64% in January and 79.12% in February. The overall loss percentage of 15.50% is weighted by the T_s of each period rather than being the arithmetic mean of the two monthly percentages, which is why it lies close to the January value.

Decomposition of the Apparent Discrepancy

Loading-point loss was calculated from a coal-getting boundary area of 6,173.28 m² (5,394.73 m² in January and 778.55 m² in February) and a residual roof-coal thickness of 0.15 m. This thickness is an assumption based on the company engineer's description of operating practice; no residual thickness was measured. It refers to the coal layer that remains at the roof contact after excavation as a safety margin against contamination by the claystone roof, and floor losses and spillage during loading are not included. Equations (6)–(8) give $LP = 1,166.75$ tons, or 4.09% of T_s .

Hauling loss was estimated from the spot-check payload, $x_u = 13 \times 1.6 \times 0.95 \times 1.26 = 24.8976$ tons/trip, and the average weighbridge tonnage, $x_{tc} = 24,114.08/1,042 = 23.1421$ tons/trip; the estimate exceeds the weighbridge average by 7.59%. Individual spot-check trips could not be matched to tickets, and across the 56 unit-date ticket records the payload ranged from 18.86 to 25.85 tons/trip. With 1,042 trips, Equations (9) and (10) give $LH = 1,829.22$ tons,

or 6.41% of Ts. Because this value depends on the fill factor, bulk density, bucket count, ticket accuracy, and moisture, it is an estimated discrepancy between two measurement points rather than a direct measurement of spillage.

Other-factor loss is the residual $LL = 4,421.95 - 1,166.75 - 1,829.22 = 1,425.98$ tons, or 5.00% of Ts. By Equation (15), hauling contributes 41.37% of the total coal losses, other factors 32.25%, and the loading point 26.39%; the rounded shares sum to 100.01%. Table 3 gives the monthly breakdown and labels the evidential status of each component.

Table 3. Decomposition of the apparent discrepancy of Seam 2, Pit B, by period

Component (status)	Loss (tons)			% of Ts			Share of CL (%)		
	Jan.	Feb.	Total	Jan.	Feb.	Total	Jan.	Feb.	Total
Loading point (assumption-based)	1,019.60	147.15	1,166.75	4.33	2.96	4.09	30.12	14.19	26.39
Hauling (estimated)	1,376.82	452.40	1,829.22	5.84	9.11	6.41	40.67	43.63	41.37
Other factors (residual)	988.72	437.26	1,425.98	4.19	8.80	5.00	29.21	42.17	32.25
Total, CL = Ts – Tc	3,385.14	1,036.81	4,421.95	14.36	20.88	15.50	100.00	100.00	100.00

Source: Research data processing, 2026. Monthly boundary areas of 5,394.73 m² (January) and 778.55 m² (February) from the company Engineering Department. The spot-check payload (24.90 tons/trip) is held constant across periods; Tc per trip is given in Table 1. Shares of individual components are rounded and may not sum exactly to 100.00.

Figure 2 visualizes the base-case components together with their sensitivity ranges and the monthly composition of the apparent discrepancy.

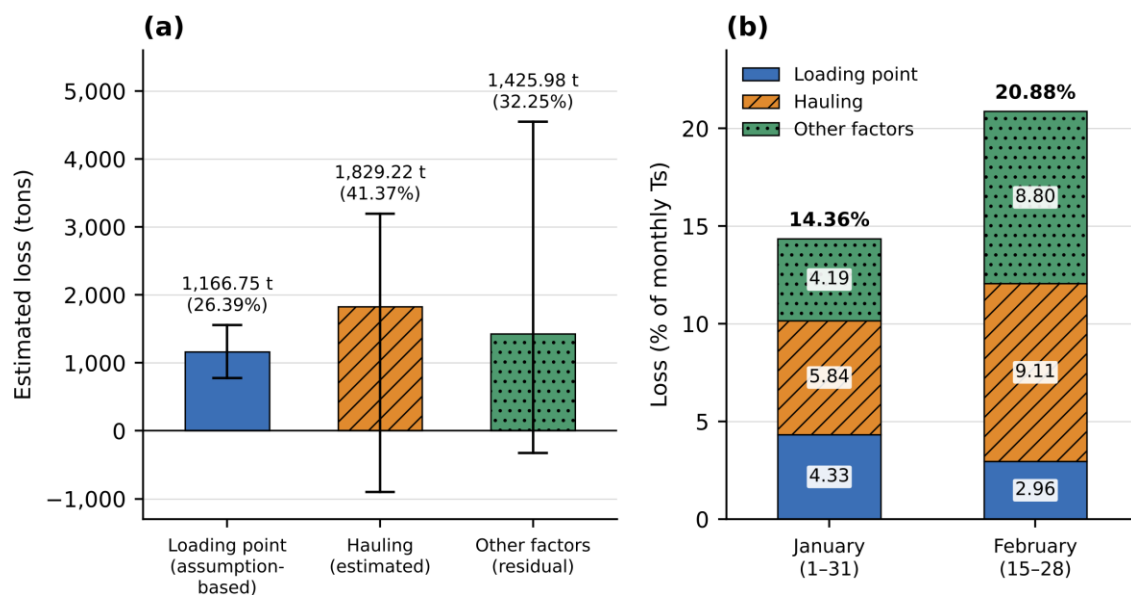


Figure 2. Component estimates of the apparent discrepancy. (a) Base-case tonnage and share of CL; whiskers show the range over roof thickness 0.10–0.20 m (loading point), bucket fill factor 0.85–1.00 (hauling), and the combined grid of both inputs (other factors). (b) Components as a percentage of monthly Ts; bar totals equal %CL. Loading point is assumption-based, hauling is estimated, and other factors are the residual $Ts - Tc - LP - LH$.

Figure 2a shows that the base-case estimates of hauling and other factors are close, whereas their sensitivity ranges overlap widely and both span zero. Figure 2b shows that most of the increase in loss from January (14.36% of Ts) to February (20.88%) lies in hauling and other factors, while the loading-point share declines. Because LP is the product of a boundary area and a constant thickness, this decline reflects the monthly area and Ts rather than a change

in practice. The base-case split is therefore one admissible allocation, not a measured distribution of coal losses.

Robustness of the Component Estimates

Because LL is the residual of Equation (13), a change in any assumed input moves tonnage among LH, LP, and LL without changing CL. Table 4 recalculates the decomposition for alternative inputs while holding Tc fixed.

Table 4. Sensitivity of the decomposition to the assumed inputs

Input change	Ts (tons)	CL (tons)	CL (% of Ts)	LP (tons)	LH (tons)	LL (tons)	Largest component
Base case (FF 0.95; roof 0.15 m; D 1.26 tons/m ³)	28,536.0	4,421.9	15.50	1,166.7	1,829.2	1,426.0	Hauling
Fill factor 0.85	28,536.0	4,421.9	15.50	1,166.7	-901.7	4,156.9	Other factors
Fill factor 0.883 (break-even)	28,536.0	4,421.9	15.50	1,166.7	0.0	3,255.2	Other factors
Fill factor 1.00	28,536.0	4,421.9	15.50	1,166.7	3,194.7	60.5	Hauling
Roof thickness 0.10 m	28,536.0	4,421.9	15.50	777.8	1,829.2	1,814.9	Hauling
Roof thickness 0.20 m	28,536.0	4,421.9	15.50	1,555.7	1,829.2	1,037.1	Hauling
Density 1.20 tons/m ³	27,177.2	3,063.1	11.27	1,111.2	593.8	1,358.1	Other factors
Density 1.32 tons/m ³	29,894.9	5,780.8	19.34	1,222.3	3,064.6	1,493.9	Hauling
Swell factor 0.74 on bucket volume (payload 18.42 tons/trip)	28,536.0	4,421.9	15.50	1,166.7	-4,916.0	8,171.2	Other factors

Source: Research data processing, 2026. FF = bucket fill factor; D = in-situ density. Negative LH values are not physical losses: they show that the assumed input gives a spot-check payload below the weighbridge average and is inconsistent with the ticket data. Tc is fixed; in the density rows, Ts, LP, and the payload estimate scale with D.

Three patterns emerge from Table 4. First, the hauling estimate is highly sensitive to the fill factor: LH is zero at FF = 0.883 and negative below it, hauling exceeds the residual only when FF is above 0.943, and other factors become the largest component at FF of 0.90 or below. At the observed mean fill factor of 0.9417, LH = 1,602.6 tons and LL = 1,652.6 tons, so other factors are slightly larger. Second, with the swell factor of 0.74 from the company worksheet, the payload falls to 18.42 tons/trip and LH becomes negative, which shows that the hauling estimate depends on the bank-density convention of Equation (11). Third, a roof thickness of 0.10–0.20 m does not change the largest component, but the margin is small: at 0.10 m hauling exceeds other factors by only 14.3 tons, and at 0.20 m the loading point exceeds other factors. Across the fill-factor and roof-thickness grid, the residual ranges from -328.4 to 4,545.8 tons, whereas density changes CL itself, from 11.27% to 19.34% of Ts. The hauling-dominant ranking, the 15.50% loss, and the sub-90% coal recovery are therefore conditional on assumed inputs that were not independently measured.

Cycle Time, Match Factor, and Haul-Road Conditions

Because the hauling estimate rests on loading and hauling operations, the cycle times recorded during the spot-check describe the conditions under which it was obtained. Table 5 summarizes the processed observations.

Table 5. Processed cycle-time observations of the loading and hauling equipment

Equipment and element	n	Mean (s)	SD (s)
<i>Excavator Sany SY365H</i>			
Digging (Tg)	30	8.49	0.63
Swing load (Tsl)	30	6.52	0.28
Dumping, excavator (Tde)	30	3.45	0.25
Swing empty (Tse)	30	5.98	0.31
Cycle time CTm	30	24.44	0.82

Equipment and element	n	Mean (s)	SD (s)
<i>Dump truck Shacman F3000</i>			
Maneuver at loading (Tml)	30	58.05	1.82
Loading (Tl)	30	332.48	9.02
Hauling (Th)	30	212.32	8.48
Maneuver at dumping (Tmd)	30	55.78	5.42
Dumping, truck (Tdt)	30	33.04	2.26
Return (Tr)	30	190.32	9.19
Cycle time CTa	30	881.99	26.19

Source: Field measurement on 20 January 2026 (processed); units DK-23, DK-27, and DK-31 (30 observations each for the excavator and the trucks; 10 per truck unit).

The excavator cycle time was $CT_m = 24.44$ s and the truck cycle time $CT_a = 881.99$ s, with loading (332.48 s) and hauling (212.32 s) the longest truck elements. With one excavator and the three trucks recorded together on 13 of the 18 ticket dates, Equation (21) gives $MF = 1.0807$; with four trucks (4 dates), $MF = 1.441$. The nine registered units were not recorded together, so $n_a = 9$ ($MF = 3.242$) does not describe the operating fleet. Queue, dispatch, and truck-specific capacity records were not available, although the company productivity worksheet lists 12 min of queueing per shift.

Field documentation along the haul road recorded loose coal fragments on the road surface, as shown in Figure 3. The photograph illustrates the observed condition only and is not used as evidence for the hauling estimate.



Figure 3. Coal fragments on the haul road of Seam 2, Pit B (illustrative field photograph; date not recorded). The photograph does not establish the composition, origin, or mass of the material. Source: field documentation, 2026.

Rainfall and Operational Downtime

Rainfall and downtime were compiled over windows that match the production records so that they could be compared with the residual component, as presented in Table 6.

Table 6. Rainfall and operational downtime over windows matched to the production records

Window	Days	Rain (mm)	Rain (mm/day)	Rain days	Rain (h)	Slippery (h)	Downtime (h)	Downtime (h/day)	LL (% of Ts)
1–31 Jan.	31	98.00	3.16	5	20.55	27.40	47.95	1.55	4.19
15–28 Feb.	14	93.00	6.64	2	5.50	18.47	23.97	1.71	8.80
1–28 Feb. ^a	28	237.50	8.48	9	29.00	48.47	77.47	2.77	–

Source: Company daily operational report, 2026 (processed). The first two windows match the production records; ^afull-month reference. Rain days have recorded rainfall above 0 mm; downtime is rain plus slippery-road hours per calendar day; LL (% of Ts) refers to the corresponding production month.

Rainfall in the February window (93.00 mm, recorded as 30.00 mm on 16 February and 63.00 mm on 22 February) averaged 6.64 mm/day, 2.10 times the January value of 3.16 mm/day. In contrast, rain days fell from 5 to 2 and rain duration from 0.66 to 0.39 h/day, while total recorded downtime rose only from 1.55 to 1.71 h/day (+10.7%); downtime is expressed per calendar day because scheduled hours were not available. Over the same windows, the residual rose from 4.19% to 8.80% of Ts. Rainfall depth, intensity (4.77 to 16.91 mm/h), duration, and downtime therefore moved in different directions between the two windows.

Recovery-Target Scenarios

Applying Equations (16)–(18) with Ts = 28,536.03 tons, Tc = 24,114.08 tons, and CL = 4,421.95 tons gives Tc(target) = 25,682.43 tons, $\Delta T = 1,568.35$ tons, and %Recovery = 35.47%, so the apparent discrepancy would have to fall from 4,421.95 tons to 2,853.60 tons. The target applies to the 28,536.03 tons of the study window and describes prevention of loss in that production, not reclamation of coal already lost. Table 7 compares the requirement with the size of each component.

Table 7. Arithmetic sufficiency of the recovery-target scenarios

Scenario	Improvement focus	Component loss (tons)	Required (tons)	Reduction of component needed (%)	Arithmetic result
1	Loading point	1,166.75	1,568.35	> 100	Insufficient even at 100% reduction
2	Hauling	1,829.22	1,568.35	85.74	Sufficient only if an 85.74% reduction is attainable
3	Combination, equal share	4,421.95	1,568.35	35.47 (each)	Sufficient only if 35.47% is attainable in each component

Source: Research data processing, 2026.

Scenario 1 cannot reach the target even if the loading-point loss were eliminated entirely, because its maximum contribution is 1,166.75 tons. Scenario 2 is arithmetically sufficient because the hauling estimate of 1,829.22 tons exceeds the requirement, but it needs an 85.74% reduction of a single estimated component. Scenario 3 reduces all three components by 35.47% each (413.82 tons at the loading point, 648.78 tons in hauling, and 505.76 tons in other factors), lowering coal losses to 2,853.60 tons (10.00%) and raising coal recovery to 90.00%; the equal split is a simplification, not an optimization. Under a uniform ceiling on attainable reduction across all components, recovery would reach 88.4% at 25%, 89.2% at 30%, and 92.3% at 50%, so the target requires reductions of at least about 35% across the estimated losses.

Discussion

Coal Recovery Against the 90% Benchmark

The coal recovery of 84.50% in [Table 2](#) lies 5.50 percentage points, or 1,568.35 tons, below the 90% benchmark of Kepmen 1827/2018. Statutory non-compliance cannot be concluded from this result for two reasons. First, the statutory metric has a reserve denominator and a planning purpose (Part C, item 11) [\[2\]](#), whereas Ts is a mined-out quantity. Second, the density and inventory issues identified in the Results remain unresolved, and the same data would give 90% at an in-situ density of 1.183 tons/m³ or lower. The result is therefore best read as an operational signal that requires reconciliation rather than as a compliance verdict.

Coal losses reported at other Indonesian pits, 22.77% [\[3\]](#), 19.43% in May 2019 [\[4\]](#), 10.35% [\[5\]](#), 10.50% at PT LDA [\[13\]](#), and 2.9–4.0% per month [\[6\]](#), are not directly comparable with the 15.50% obtained here. The studies differ in denominator (reserve or mined-out coal), moisture basis, measurement boundary (pit to stockpile or pit to barge [\[7\]](#)), observation period, and method, as well as in the dominant component, which was the loading point in [\[4\]](#) and [\[5\]](#) but hauling in the present base case. What the comparison does show is that sub-90% values are reported repeatedly, and that conditions within the seam itself, such as impurities, have also been reported to reduce mining recovery [\[20\]](#). Since each of these sources applies its own boundary, the contribution of the present study lies less in the magnitude of the loss than in making explicit how strongly that magnitude depends on measurement inputs.

Hauling: Largest Base-Case Estimate

In the base case ([Table 3](#)), hauling has the largest estimated share (41.37%, 1,829.22 tons), followed by other factors (32.25%) and the loading point (26.39%). This differs from the loading-point dominance reported in [\[4\]](#) and [\[5\]](#), but the difference is conditional. Because $LL = CL - LP - LH$, the shares are dependent, and hauling remains largest only for fill factors above 0.943 ([Table 4](#)), marginally higher than the observed mean of 0.9417, at which other factors are slightly larger. The positive deviation of 7.59% between the spot-check estimate and the weighbridge average is compatible with spillage or overloading, but a systematic overestimate of payload through the fill factor, bulk density, or bucket count would produce the same sign. Without independent calibration or paired loading–destination measurements, LH remains an estimated allocation, and hauling cannot be identified as the dominant physical loss mechanism.

The operating conditions in [Table 5](#) do not resolve this ambiguity. An MF of 1.0807 for the three-truck fleet indicates a slight excess of hauling capacity, and the 12 min of queueing per shift in the productivity worksheet is compatible with, but does not demonstrate, a link between MF and queueing, overloading, or coal loss; that link remains a hypothesis. Match factors reported for other loader–hauler fleets, 0.90 [\[19\]](#) and 0.96 [\[17\]](#), are below one and show only that loader–hauler mismatch is common [\[21\]](#), [\[22\]](#); they do not corroborate an MF above one here. Studies on truck factor [\[15\]](#), road grade and fuel consumption [\[23\]](#), and haul-road geometry [\[24\]](#), [\[25\]](#) address productivity and are therefore indirect evidence that does not validate coal loss.

The monthly pattern adds a further qualification. The estimated hauling loss rose from 5.84% of Ts in January to 9.11% in February, corresponding to 40.67% and 43.63% of coal losses ([Figure 2b](#)). Because the spot-check estimate is held constant at 24.90 tons/trip, this increase arises entirely from the lower ticket tonnage per trip, 23.31 tons/trip in January and 22.33 tons/trip in February ([Table 1](#)), and whether it reflects spillage, smaller loads, or measurement and moisture effects cannot be resolved from the data. Its coincidence with the wetter February window ([Table 6](#)) is consistent with reports that rain-induced slippery roads increase the risk of load spillage [\[16\]](#) and with the influence of rainfall on hauling production at

another open-pit coal mine in East Kalimantan [26]. With only two windows, however, it is a pattern match and not evidence of causation, and the loose coal visible in Figure 3 likewise cannot be converted into a loss tonnage.

Other Factors: Residual and Rainfall

Other factors are not measured directly. As the residual of the subtraction, they absorb every error of Ts, Tc, LP, and LH, including timing offsets, density and moisture effects, spot-check estimation error, and the assumed roof thickness, and they may also include unidentified factors. The residual of 1,425.98 tons (32.25%) is therefore not an independently measured rainfall loss. Its uncertainty cannot be estimated statistically because Ts, Tc, LP, and LH share inputs (density enters Ts, LP, and LH) and no repeated measurements exist. The bounded sensitivity analysis in Table 4, in which the residual ranges from –328.4 to 4,545.8 tons, is the only available indication of its range, and the ranking and reduction targets are conditional on those inputs.

The rainfall comparison in Table 6 must be read within the same limits. The residual roughly doubled, from 4.19% to 8.80% of Ts, while rainfall per day rose 2.10 times, yet rain days, rain duration, and downtime did not move in the same direction. None of these indicators can therefore be identified as the better proxy for the residual, and with two windows no statistical test is possible. A mechanism in which waterlogged coal and fine fractions mix with mud [16], runoff erodes uncovered coal fronts, and wet plastic claystone adheres to the coal could contribute to the residual, but it is presented here as a hypothesis to be tested with matched daily data.

Loading Point: Assumption-Based Estimate

The base-case loading-point loss is 1,166.75 tons (4.09% of Ts and 26.39% of coal losses). It is the product of a surveyed boundary area, an assumed roof thickness, and the density, and it counts only the layer left at the roof. Floor losses, which were not calculated because bore-log data were limited, and spillage during loading are excluded, so 1,166.75 tons is a partial rather than a complete loading-point loss. Table 4 shows its sensitivity to the assumed thickness: 777.8 tons at 0.10 m and 1,555.7 tons at 0.20 m. The monthly decrease of LP from 4.33% to 2.96% of Ts (Table 3) follows from the monthly boundary area and Ts under a constant thickness; in the absence of operator-performance data or measured thickness, it is not evidence of improved operator consistency. Leaving 0.10 m instead of 0.15 m, the practice reported in [5], would recover at most 388.92 tons, which is 24.90 tons less than the 413.82 tons that Scenario 3 assigns to this component (Table 7).

Implications for Improvement Efforts

The scenarios in Table 7 narrow the options. The loading point alone is arithmetically insufficient, and hauling alone would require an 85.74% reduction of an estimated quantity. Because no attainable-reduction limit was measured, Scenario 2 cannot be shown to be impossible, but it is improbable, as it would remove most of a discrepancy that may partly reflect payload-estimation bias. Improvement would therefore have to address several components at once. Table 8 lists candidate actions by estimated share, with their type, constraints, and monitoring indicators. Because the order of the shares is conditional (Table 4), the table is a starting point for verification, not a ranking of effectiveness.

Table 8. Candidate improvement actions and verification needs

Order	Component (estimated share)	Candidate action	Type	Constraint, evidence needed, and monitoring indicator
1	Hauling (41.37%, estimated)	Standardize truck loads to vessel capacity; install tarp covers; maintain the haul road to the criteria of Kepdirjen 226/2019 [27]	Preventive	Paired loading–ticket data are needed to show how much of LH is physical loss; monitor ticket tons per trip and coal spilled along the road; cost and resources not yet estimated
2	Other factors (32.25%, residual)	Drainage with sumps and water channels at the mining front and loading point; geotextile; reschedule loading during high rainfall	Preventive; recovery of mud-contaminated coal not assessed	The residual is not a measured rain loss; monitor downtime per day and coal delivered per rainy day; quality of any recovered coal not yet assessed
3	Loading point (26.39%, assumption-based)	Horizontal excavation; floor finishing; operator competence at the roof–floor contact	Preventive	The 0.15 m layer is a safety margin against dilution by the claystone roof; reducing it requires surveyed roof control and coal-quality (ash) monitoring; monitor residual thickness by survey

Source: Research data processing, 2026.

The haul-road action is supported by studies showing that road geometry affects hauling productivity [24], [25] and by haul-road redesign work that evaluates road width, curve widening, and superelevation against operating standards [28]. Kepdirjen 226/2019 (Appendix I, Part D, item 3 letter b, points 2–4) sets a maximum gradient of 12%, above which a technical study is required, and requires road width, curve radius, and superelevation adequate for passing vehicles [27]; the criteria applied at the site were not available. Drainage management and weather anticipation are consistent with mine-drainage studies that emphasize adequately sized surface-runoff channels [29], [30]. Loading-point excavation is constrained by the minimum coal thickness that must be left, and reducing that thickness raises dilution risk and requires coal-quality checks.

Wider evidence supports treating these actions as candidates rather than solutions. Recovery of coal classified as loss has been examined in a different mining setting [31], and period-specific rather than constant recovery values have been proposed for long-term planning [32], but neither tests the actions in Table 8. System-dynamics and agent-based studies of Indonesian coal producers relate the gap between planned and actual production to the stripping ratio [33] and to mining-sequence changes, geological-model accuracy, and operational losses [34]; these studies address plan-versus-actual production rather than a stage-by-stage decomposition of a survey-to-weighbridge discrepancy, so they complement rather than validate the decomposition used here. Any action would also require estimates of cost, resources, and timeline [35], together with an assessment of safety risk, before its feasibility could be judged.

Research Limitations

The apparent discrepancy $T_s - T_c$ is not an independent measurement of physical loss: inventories, rehandling, and carryover were not reconciled, and the weighbridge calibration and moisture basis, survey instrument calibration, and Minescape settings were not documented. The density of 1.26 tons/m³ and the roof thickness of 0.15 m were constants without a documented measurement basis, and the 90% benchmark was applied to a mined-out rather than a reserve denominator. The hauling estimate rests on 30 trips by three of the nine registered units, a single visually assessed fill factor, and no matching to tickets, with all

observations taken on one day in January and assumed to hold for both months, although February was wetter. Floor losses and loading spillage were not calculated, and the rainfall comparison uses only two windows. Attainable reductions, costs, and constraints were not measured, so the scenarios remain arithmetic, and the results apply only to the studied seam and period.

CONCLUSION

Reconciliation of the survey-based in-situ tonnage with the weighbridge tonnage of Seam 2, Pit B, for January–February 2026 gave an apparent discrepancy of 4,421.95 tons (15.50%) and a coal recovery of 84.50%, which is 5.50 percentage points below the 90% benchmark. The shortfall is an apparent rather than a reconciled loss, because inventory and carryover were not reconciled and the result depends on the assumed density, and statutory non-compliance cannot be concluded because the regulatory metric is production divided by reserves and the 90% value is a planning figure. Allocated to operational stages, the discrepancy comprised the loading point (1,166.75 tons, assumption-based), hauling (1,829.22 tons, estimated), and other factors (1,425.98 tons, residual). Hauling had the largest base-case share (41.37%), but this ranking holds only at bucket fill factors above 0.943, marginally above the observed mean of 0.9417, and the hauling estimate vanishes at 0.88. The co-movement of rainfall and the residual between two windows is descriptive only.

Reaching 90% recovery would require 1,568.35 tons, a 35.47% reduction of the apparent discrepancy. The loading point alone is insufficient, hauling alone would require an 85.74% reduction, and an equal 35.47% reduction in all three components is an arithmetic illustration that has not been implemented or validated. Before the framework is used for improvement planning, weighbridge calibration, paired loading–ticket measurements, inventory reconciliation at each cut-off, measured roof thickness, density with its moisture basis, and rainfall and downtime records over matched windows should be obtained.

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REFERENCES

- [1] M. J. Ntsekhe and W. W. de Graaf, "An investigation into mining coal losses at Klipspruit Colliery," *Journal of the Southern African Institute of Mining and Metallurgy*, vol. 124, no. 5, pp. 245–251, 2024, doi: 10.17159/2411-9717/1101/2024.
- [2] Kementerian Energi dan Sumber Daya Mineral Republik Indonesia, Keputusan Menteri Energi dan Sumber Daya Mineral Nomor 1827 K/30/MEM/2018 tentang Pedoman Pelaksanaan Kaidah Teknik Pertambangan yang Baik. Jakarta, Indonesia: Kementerian ESDM, 2018.
- [3] R. Julianti, "Analisis coal losses pada aktivitas penambangan batubara di Pit 1B PT. Hutamas Koado, Kabupaten Sarolangun, Provinsi Jambi," Undergraduate thesis, Universitas Negeri Padang, Padang, Indonesia, 2025.
- [4] A. Irfandy, A. Triantoro, and S. Melati, "Analisis coal losses pada kegiatan penambangan di Pit Inul Middle Panel 3 PT. Kaltim Prima Coal," *Jurnal HIMASAPTA*, vol. 6, no. 2, pp. 57–65, 2021, doi: 10.20527/jhs.v6i2.3960.

-
- [5] A. D. Ananda, "Analisis coal losses dari proses coal getting untuk meningkatkan nilai coal mining recovery di Pit Alam 1-3 PT. Muara Alam Sejahtera, Desa Muara Maung, Kecamatan Merapi Barat, Kabupaten Lahat, Provinsi Sumatera Selatan," Undergraduate thesis, Universitas Negeri Padang, Padang, Indonesia, 2023.
- [6] T. C. Jabi, Y. Rumbino, and I. F. Krisnasiwi, "Analisis kehilangan batubara pada kegiatan penambangan batubara di PT UN Tbk," *Jurnal Teknologi*, vol. 19, no. 1, pp. 40–46, 2025. [Online]. Available: https://ejurnal.undana.ac.id/index.php/jurnal_teknologi/article/view/22339
- [7] F. K. Zaky and R. Anarta, "Analisa tingkat kehilangan batubara (coal losses) dari proses coal getting sampai barging di PT. Bhumi Sriwijaya Perdana Coal, Kecamatan Tungkal Jaya, Kabupaten Musi Banyuasin, Provinsi Sumatera Selatan," *Bina Tambang*, vol. 7, no. 3, pp. 65–76, 2022, doi: 10.24036/bt.v7i3.120200.
- [8] S. Kurniawan and L. Okdinawati, "Optimizing coal production estimates: Balancing topographic surveys method and truck counts method at Pit Kress, PT. Bordun Indie, South Kalimantan, Indonesia," *Asian Journal of Engineering, Social and Health*, vol. 3, no. 11, pp. 2505–2519, 2024, doi: 10.46799/ajesh.v3i11.446.
- [9] Fadli and Wulan, "Optimalisasi sequence penambangan batubara PT Caritas Energi Indonesia site PT Batubara Jambi Lestari, Kecamatan Sarolangun, Kabupaten Muaro Jambi, Provinsi Jambi," *Jurnal Geomine*, vol. 13, no. 2, pp. 95–101, 2025, doi: 10.33096/4wm70r74.
- [10] R. Hutmi and H. Prabowo, "Perhitungan perbandingan tonase bauksit menggunakan data truck count dan tonase hasil analisa laboratorium di Bauxite Processing Plant 1 dan 2 PT. Jaga Usaha Sandai-Site Sandai, Sandai Kiri, Kecamatan Sandai, Kabupaten Ketapang, Kalimantan Barat," *Bina Tambang*, vol. 7, no. 1, pp. 1–11, 2022, doi: 10.24036/bt.v7i1.117653.
- [11] K. A. Suryawan, *Manajemen Alat Berat*. Yogyakarta, Indonesia: Deepublish, 2019.
- [12] J. Lu, Z. Yao, Q. Bi, and X. Li, "A neural network-based approach for fill factor estimation and bucket detection on construction vehicles," *Computer-Aided Civil and Infrastructure Engineering*, vol. 36, no. 12, pp. 1600–1618, 2021, doi: 10.1111/mice.12675.
- [13] A. W. Seuk, Y. Rumbino, and I. F. Krisnasiwi, "Analisis coal losses pada kegiatan penambangan batubara di Pit Kungkulan PT. LDA," *Jurnal Teknologi*, vol. 19, no. 1, pp. 47–51, 2025. [Online]. Available: https://ejurnal.undana.ac.id/index.php/jurnal_teknologi/article/view/22340
- [14] A. P. P. Putra, S. Hariyadi, M. Dwiantoro, T. B. Amperadi, and S. Sujiman, "Geological modeling of coal seams in Block P24, PT Indominco Mandiri, East Kutai Regency," *Jurnal Teknik Pertambangan*, vol. 25, no. 2, pp. 90–101, 2025, doi: 10.36873/jtp.v25i2.20188.
- [15] N. Zainuddin, "Studi truck factor bottom ore fleet area PT Vale Indonesia Tbk," *Jurnal Geomine*, vol. 14, no. 2, pp. 67–73, 2026, doi: 10.33096/11yq4991.
- [16] G. H. Khoso, S. M. Pathan, M. S. Memon, and Z. A. Shaikh, "Assessing the rainfall implications on surface coal mining operations: Thar case study," *Quaid-e-Awam University Research Journal of Engineering, Science & Technology*, vol. 21, no. 2, pp. 29–38, 2023, doi: 10.52584/QRJ.2102.04.
- [17] S. R. Waruwu, M. A. O. Tolayuk, and Novalisae, "Perhitungan match factor alat gali muat di Pit Bantian 55-B PT. Indo Muro Kencana (IMK)," *Jurnal Teknik Pertambangan*, vol. 25, no. 1, pp. 1–7, 2025, doi: 10.36873/jtp.v25i1.14014.
- [18] M. R. Qinthara, M. A. Azizi, E. F. Budhya, and I. Marwanza, "Pengaruh efisiensi kerja terhadap konsumsi bahan bakar alat gali muat dan angkut," *Indonesian Mining and Energy Journal*, vol. 5, no. 1, pp. 24–32, 2022. [Online]. Available: <https://ejournal.trisakti.ac.id/index.php/imej/article/view/13778>
- [19] D. Anggara, Franto, and Guskarnali, "Evaluasi match factor alat gali-muat dan angkut untuk meningkatkan produktivitas stripping overburden PT Cipta Kridatama," *Jurnal HIMASAPTA*, vol. 9, no. 1, pp. 13–20, 2024, doi: 10.20527/jhs.v9i1.9373.
- [20] M. Asof, A. Triando, and M. Puspita, "Analisis mining recovery penambangan batubara akibat adanya pengotor (impurities) pada Lapisan A2 dan B di PT Bara Alam Utama," *Jurnal*
-

- Pertambangan, vol. 7, no. 1, pp. 1–4, 2023. [Online]. Available: <https://ejournal.ft.unsri.ac.id/index.php/JP/article/view/1587>
- [21] H. Prabowo and U. Z. D. Marcelino, “Kajian teknis produktifitas dan keserasian excavator dengan dump truck pada kegiatan coal getting Seam 18 PT. Kurnia Alam Investama Kabupaten Batanghari Provinsi Jambi,” *CIVED*, vol. 10, no. 2, pp. 398–408, 2023, doi: 10.24036/cived.v10i2.397.
- [22] R. Fikri and M. Gusman, “Analysis match factor loader and hauler for activities overburden removal using the queue method at PT. Andalan Artha Primanusa Jobsite PT. Budi Gema Gempita, South Sumatera Province,” *Bina Tambang*, vol. 9, no. 1, pp. 27–33, 2024, doi: 10.24036/bt.v9i1.127642.
- [23] H. Prabowo and C. Febriani, “Analysis of the relationship between road slope and total resistance to fuel consumption of Sany SKT 90S dump truck,” *MOTIVECTION: Journal of Mechanical, Electrical and Industrial Engineering*, vol. 5, no. 2, pp. 397–414, 2023, doi: 10.46574/motivection.v5i2.242.
- [24] M. Zara and H. Prabowo, “Kajian teknis geometri jalan angkut dan pengaruhnya terhadap produksi alat angkut pada penambangan batu andesit di PT. Ansar Terang Crushindo, Kecamatan Pangkalan Koto Baru, Sumatera Barat,” *Bina Tambang*, vol. 5, no. 5, pp. 20–31, 2020, doi: 10.24036/bt.v5i5.110157.
- [25] R. N. Fitriadi, Iswandaru, and E. Moralista, “Pengaruh geometri jalan terhadap produktivitas alat angkut,” *Jurnal Riset Teknik Pertambangan*, vol. 4, no. 1, pp. 41–48, 2024, doi: 10.29313/jrtp.v4i1.3821.
- [26] Nurhidayatullah Am, S. D. Devy, L. L. Respati, A. Ismail, T. Trides, and A. Winarno, “Pengaruh curah hujan terhadap produksi alat angkut batubara PT Bima Nusa Internasional Pit Susubang Jobsite PT Kideco Jaya Agung, Kabupaten Paser, Kalimantan Timur,” *Globe: Publikasi Ilmu Teknik, Teknologi Kebumian, Ilmu Perkapalan*, vol. 3, no. 3, pp. 14–35, 2025, doi: 10.61132/globe.v3i3.936.
- [27] Kementerian Energi dan Sumber Daya Mineral Republik Indonesia, Keputusan Direktur Jenderal Mineral dan Batubara Nomor 226.K/30/DJB/2019 tentang Petunjuk Teknis Pelaksanaan Konservasi Batubara dalam rangka Pengendalian Kehilangan dan Dilusi pada Kegiatan Penambangan serta Pengelolaan Batubara Kualitas Rendah. Jakarta, Indonesia: Direktorat Jenderal Mineral dan Batubara, 2019.
- [28] D. Lestari, S. R. Yanti, T. G. Saldy, and R. A. P. Heriawan, “Geometric redesign and cut-and-fill volume estimation of a non-compliant mine haul road at Pit Banko Tengah A, South Sumatra,” *MOTIVECTION: Journal of Mechanical, Electrical and Industrial Engineering*, vol. 8, no. 2, pp. 125–142, 2026, doi: 10.46574/motivection.v8i2.583.
- [29] M. P. Secilia, M. Bisri, and U. Andawayanti, “Studi evaluasi sistem drainase air limpasan permukaan di Site Gurimbang Mine Operation PT Berau Coal,” *Jurnal Teknologi dan Rekayasa Sumber Daya Air*, vol. 3, no. 2, pp. 719–732, 2023, doi: 10.21776/ub.jtresda.2023.003.02.061.
- [30] D. J. Rianto, R. A. Ilahi, and A. Marwadi, “Perencanaan mine drainage pada lahan bekas tambang batubara: Studi kasus PT Tambulun Pangian Indah,” *Jurnal HIMASAPTA*, vol. 8, no. 3, pp. 141–146, 2023, doi: 10.20527/jhs.v8i3.9220.
- [31] B. Cao, X. Guo, J. Duan, Z. Zhang, G. Wu, K. Dong, and Y. Yin, “Recovery of compaction resources in internal dump of gently inclined composite coal seam open-pit mine,” *Scientific Reports*, vol. 14, Art. no. 25958, 2024, doi: 10.1038/s41598-024-76960-3.
- [32] J. F. C. da Mata, A. S. Nader, and D. B. Mazzinghy, “A case study of incorporating variable recovery and specific energy in long-term open pit mining,” *Mining*, vol. 3, no. 2, pp. 367–386, 2023, doi: 10.3390/mining3020022.
- [33] O. Bakkula, D. Wibisono, and M. Siallagan, “Examining the drivers of changes in stripping ratio in open pit coal mining: A system dynamics model to optimize the coal discrepancy,” *Discover Applied Sciences*, vol. 7, no. 6, Art. no. 627, 2025, doi: 10.1007/s42452-025-07227-3.

-
- [34] O. Bakkula, D. Wibisono, M. H. Basri, and M. Siallagan, "Towards resilience in the value chain of coal mining upstream: An agent-based modeling and simulation to improve coal discrepancy," *Discover Applied Sciences*, vol. 7, no. 1, Art. no. 22, 2025, doi: 10.1007/s42452-024-06375-2.
- [35] N. A. Ardianti and H. Prabowo, "Estimasi biaya dan evaluasi kebutuhan alat muat dan alat angkut terhadap efisiensi penambangan batubara pada tambang terbuka PT. Allied Indo Coal Jaya, Sawahlunto," *Bina Tambang*, vol. 5, no. 2, pp. 22–31, 2020, doi: 10.24036/bt.v5i2.107815.

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